Claims

1. A MEMS device, the MEMS device comprising:

a substrate having a surface,

an actuable element at least partially formed from the substrate, and

an electromagnetic actuator disposed on the substrate for selectively applying a first force to the actuable element to displace the actuable element along a path.

2. The MEMS device of claim 1, wherein the actuable element has a base and an arm coupled thereto, the base of the actuable element including a portion comprised of a magnetic material.

3. The MEMS device of claim 2, wherein the magnetic material is comprised of at least one of a permanent magnetic material and a soft magnetic material.

4. The MEMS device of claim 2, wherein the magnetic material is comprised of at least one of ferrites, remalloy, vicalloy, AlNiCo, Co, CoPt, a rare earth metal, NiFe (permalloy), CoFe (permendur), CoZr, FeN, AlSiFe (sendust), NiFeMo (supermalloy), NiFeCuCr (mumetal), NiFeCo, CoFeB, CoFeV (supermendur), CoFeCr (hiperco), CoZrTa, FeAlN, FeTaN, and combinations thereof.

5. The MEMS device of claim 2, wherein the portion of the base comprised of a magnetic material has a length in a direction substantially parallel to the path and a cross-section having a first extent, the first extent of the cross-section varying over the length.

6. The MEMS device of claim 2, wherein the portion of the base comprised of a magnetic material has a length in a direction substantially parallel to the path and a cross-section having a first extent, the first extent of the cross-section being substantially constant over the length.

7. The MEMS device of claim 6, wherein the electromagnetic actuator comprises an electrically conductive coil.

8. The MEMS device of claim 7, wherein the path of the actuable element passes through a gap in the coil.

9. The MEMS device of claim 7, wherein the coil is comprised of a conductive material having a resistivity less than approximately 1×10^{-7} Ωm at 20° C.

10. The MEMS device of claim 7, wherein the coil is comprised of at least one of copper, aluminum, gold, silver, and alloys thereof.

11. The MEMS device of claim 7, wherein the coil has an inductance of at least approximately 50 nH.

12. The MEMS device of claim 7, wherein the coil has a circumference and a cross-section having a first extent, the first extent of the cross-section being substantially constant over the circumference.

13. The MEMS device of claim 7, wherein the coil has a circumference and a cross-section having a first extent, the first extent of the cross-section varying over the circumference.

14. The MEMS device of claim 7, wherein the electromagnetic actuator further comprises a magnetic core about which the electrically conductive core is wound.

15. The MEMS device of claim 14, wherein the core has a magnetic permeability of at least approximately 4×10^3.

16. The MEMS device of claim 14, wherein the core is comprised of a soft magnetic material.

17. The MEMS device of claim 16, wherein the soft magnetic material includes at least one of NiFe (permalloy), CoFe (permendur), CoZr, FeN, AlSiFe (sendust), NiFeMo (supermalloy), NiFeCuCr (mumetal), NiFeCo, CoFeB, CoFeV (supermendur), CoFeCr (hiperco), CoZrTa, FeAlN, FeTaN, and combinations thereof.

18. The MEMS device of claim 14, wherein the core has a circumference and a cross-section having a first extent, the first extent of the cross-section being substantially constant over the circumference.

19. The MEMS device of claim 14, wherein the core has a circumference and a cross-section having a first extent, the first extent of the cross-section varying over the circumference.

20. The MEMS device of claim 14, wherein the core has a first core end and a second core end, the first core end and the second core end being separated by a core gap, the path of the actuable element extending at least partially into the core gap.

21. The MEMS device of claim 20, wherein the core gap has an extent in a direction substantially perpendicular to the path of at least approximately 5 μm.

22. The MEMS device of claim 20, wherein the coil has a first coil end and a second coil end, the first coil end and the second coil end being separated by a coil gap, the coil gap having an extent equal to or greater than an extent of the core gap.

23. The MEMS device of claim 14, wherein the coil continuously covers at least approximately 80% of the surface area of the core.

24. The MEMS device of claim 14, wherein the coil includes at least ten windings about the core.

25. The MEMS device of claim 1, wherein the path extends substantially parallel to the substantially planar surface of the substrate.

26. The MEMS device of claim 1, further comprising a clamp for selectively clamping the actuable element at a desired position on the path.

27. The MEMS device of claim 26, wherein the clamp is coupled to at least one of the MEMS actuator and the actuable element.

28. The MEMS device of claim 1, further comprising a stop for selectively inhibiting displacement of the actuable element beyond a desired position on the path.

29. The MEMS device of claim 28, wherein the stop is coupled to the substrate.

30. The MEMS device of claim 28, wherein the stop comprises a wall disposed on the substrate, the wall protruding at least partially into the path.

31. The MEMS device of claim 1, further comprising a control mechanism operable to selectively apply a second force to the actuable element in a direction opposite to the first force.

32. The MEMS device of claim 31, wherein the control mechanism is formed from the substrate.

33. The MEMS device of claim 32, wherein the control mechanism is coupled to the actuable element at one end and the substrate at another end.

34. The MEMS device of claim 31, wherein the control mechanism comprises at least one cantilever.

35. The MEMS device of claim 34, wherein the at least one cantilever extends substantially parallel to the surface of the substrate.

36. The MEMS device of claim 34, wherein the control mechanism comprises a plurality of cantilevers.

37. The MEMS device of claim 36, wherein the actuable element has a first side, and the plurality of cantilevers are coupled to the first side.

38. The MEMS device of claim 36, wherein the actuable element has a first side and a second side disposed opposite to the first side and at least one cantilever is coupled to the first side and at least one cantilever is coupled to the second side.

39. The MEMS device of claim 38, wherein at least one cantilever coupled to the first side of the actuable element is substantially coaxial with at least one cantilever coupled to the second side of the actuable element.

40. The MEMS device of claim 31, wherein the control mechanism comprises at least one spring coupled to the actuable element at one end and the substrate at another end.

41. The MEMS device of claim 31, wherein the control mechanism comprises a plurality of springs, each spring coupled at one end to the actuable element and at another end to the substrate.

42. The MEMS device of claim 31, wherein the control mechanism comprises a second MEMS actuator.

43. The MEMS device of claim 42, wherein the second MEMS actuator is a second electromagnetic MEMS actuator.

44. The MEMS device of claim 43, wherein the second electromagnetic MEMS actuator includes a magnetic core and an electrically conductive coil wound about the core.

45. The MEMS device of claim 1, wherein the MEMS device has an extent in a direction substantially perpendicular to the surface of the substrate of less than approximately 50 μm.

46. The MEMS device of claim 1, further comprising a suspension mechanism for selectively controlling the location of the actuable element in a direction substantially perpendicular to the surface of the substrate.

47. The MEMS device of claim 46, wherein the suspension mechanism comprises at least one of one or more clamps, one or more springs, or one or more cantilevers.

48. The MEMS device of claim 46, wherein the suspension mechanism comprises one or more permanent magnets.

49. The MEMS device of claim 46, wherein the suspension mechanism comprises one or more electromagnets.

50. A MEMS device comprising:

a substrate,

an actuable element,

an actuator disposed on the substrate for selectively applying a first force to the actuable element to displace the actuable element along a path, and

at least one cantilever coupled to the actuable element at one end and the substrate at another end to control displacement of the actuable element along the path.

51. The MEMS device of claim 50, wherein the actuator is disposed on the surface of the substrate.

52. The MEMS device of claim 50, wherein the actuable element includes an optical element for attenuating an optical beam lying in the path.

53. The MEMS device of claim 52, wherein the optical beam comprises at least one of a light beam and a particle beam.

54. The MEMS device of claim 52, wherein the optical beam lies in a plane substantially parallel to the surface of the substrate.

55. The MEMS device of claim 54, wherein the optical beam lies in a plane substantially perpendicular to the surface of the substrate.

56. The MEMS device of claim 50, wherein the optical element is a shutter for selectively blocking the optical beam.

57. The MEMS device of claim 56, wherein the shutter includes at least one of an opaque, a semi-transparent, a semi-reflective, and a reflective surface.

58. The MEMS device of claim 50, wherein the at least one cantilever extends substantially parallel to the surface of the substrate.

59. The MEMS device of claim 50, wherein the actuable element has a first side, and a plurality of cantilevers are coupled to the first side.

60. The MEMS device of claim 50, wherein the actuable element has a first side and a second side disposed opposite to the first side, and at least one cantilever is coupled to the first side and at least one cantilever is coupled to the second side.

61. The MEMS device of claim 60, wherein at least one cantilever coupled to the first side is substantially coaxial with at least one cantilever coupled to the second side.

62. The MEMS device of claim 50, wherein at least a portion of the actuable element is formed from the substrate.

63. The MEMS device of claim 50, wherein at least a portion of the cantilever is formed from the substrate.

64. A MEMS device comprising:

a substrate,

first and second actuable elements,

a first MEMS actuator for selectively applying a first force to the first actuable element to displace the first actuable element along a first path,

a second MEMS actuator for selectively applying a second force to the second actuable element to displace the second actuable element along a second path,

a first cantilever coupled to the first actuable element for controlling the displacement of the first actuable element along the first path, and

a second cantilever coupled to the second actuable element for controlling the displacement of the second actuable element along the second path.

65. The MEMS device of claim 64, further comprising a first optical element coupled to the first actuable element and a second optical element coupled to the second actuable element.

66. The MEMS device of claim 65, wherein the first path and the second path are positioned to intersect an optical beam.

67. The MEMS device of claim 66, wherein the first optical element and the second optical element may each be selectively displaced along the first and second path, respectively, to selectively attenuate the optical beam.

68. A MEMS device disposed on a substrate having at least a top layer, the MEMS device comprising:

an actuable element comprising a base and a generally elongated arm extending from the base, the base including a magnetic material, at least a portion of the actuable element being formed from the top layer of the substrate, and

an electromagnetic MEMS actuator comprising an electrically conductive coil arranged to generate a magnetic field within a gap formed by spaced apart ends of the coil upon application of a current to the coil, the base of the actuable element being positioned proximate the gap such that the actuable element can be displaced relative to the gap upon application of the magnetic field on the magnetic material.

69. A MEMS device disposed on a substrate, the MEMS device comprising:

an actuable element comprising a base and a generally elongated arm extending from the base, the base including a magnetic material,

an electromagnetic MEMS actuator comprising an electrically conductive coil arranged to generate a magnetic field within a gap formed by spaced apart ends of the coil upon

application of a current to the coil, the base of the actuable element being positioned proximate the gap such that the actuable element can be displaced relative to the gap upon application of the magnetic field on the magnetic material, and

a cantilever attached to the substrate at one end and the arm of the actuable element at another end.

70. A method of fabricating a MEMS device on a substrate, the method comprising:

constructing an electromagnetic MEMS actuator on the surface of the substrate by building an electrically conductive coil on the surface of the substrate, the coil being arranged to form a gap between two ends of the coil, and

forming an actuable element from a layer of the substrate at position on the substrate to facilitate displacement of at least a portion of the actuable element relative to the gap upon activation of the electromagnetic MEMS actuator.

71. The method of claim 70 further comprising constructing a cantilever on the substrate, the cantilever being coupled at one end to the substrate and at another end to the actuable element.

72. The method of claim 71, wherein constructing the cantilever comprises forming the cantilever from a layer of the substrate.

73. The method of claim 70, wherein constructing the electromagnetic MEMS actuator further includes building a core of magnetic material within the electrically conductive coil such that the coil winds about the core.

74. A method of fabricating a magnetically actuable MEMS component from a substrate, the method comprising:

applying and patterning a magnetic layer of the MEMS component on the substrate,

applying and patterning a mask layer on the substrate to define a shape of the MEMS component,

etching a top layer of the substrate in accordance with the mask to form the MEMS component, and

releasing the MEMS component from the substrate to permit displacement of the MEMS component relative to the substrate.

75. The method of claim 74, wherein applying and patterning a magnetic layer of the MEMS component on the substrate comprises

applying a layer of magnetic material to a top layer of the substrate,

applying a layer of a first material to the layer of magnetic material to form a first mask layer over the layer of magnetic material,

applying a layer of a second material to the first mask layer to form a second mask layer,

patterning the second mask layer to form a first window through the second mask layer to the first mask layer,

patterning the first mask layer through the first window to form a second window through the first layer to the layer of magnetic material,

removing the second mask,

patterning the layer of magnetic material through the second window to remove magnetic material exposed through the second window, and

removing the first mask.

76. The method of claim 75, wherein the first material is resistant to high-powered non-reactive ion beam etching.

77. The method of claim 76, wherein the first material is alumina or silica.

78. The method of claim 75, wherein the second material is a photo-resist material.

79. The method of claim 75, wherein patterning the layer of magnetic material includes non-reactive ion beam etching the layer of magnetic material.

80. The method of claim 75, wherein patterning the second mask layer includes reactive ion beam etching the second mask layer.

81. The method of claim 74, wherein releasing the MEMS component from the substrate comprises etching away at least a portion of a second layer of the substrate beneath the top layer.

82. The method of claim 74, further comprising applying and patterning a spacer layer on the substrate before applying a layer of magnetic material on the substrate.

83. The method of claim 74, wherein the magnetic layer comprises at least one of ferrites, remalloy, vicalloy, AlNiCo, Co, CoPt, a rare earth metal, NiFe (permalloy), CoFe (permendur), CoZr, FeN, AlSiFe (sendust), NiFeMo (supermalloy), NiFeCuCr (mumetal), NiFeCo, CoFeB, CoFeV (supermendur), CoFeCr (hiperco), CoZrTa, FeAlN, FeTaN, and combinations thereof.

84. A method of fabricating a MEMS electromagnet on a substrate, the method comprising:

applying a lower layer of electrically conductive material to the substrate,

patterning the lower layer to form a lower set of winding elements,

applying a second layer of electrically conductive material over the lower set of winding elements,

patterning the second layer to form connectors over the winding elements of the lower set of winding elements,

applying a third layer of electrically conductive material over the connectors, and

patterning the third layer to form an upper set of winding elements that are electrically connected to the winding elements of the lower set of winding elements by the connectors.

85. The method of claim 84, further comprising applying a metal seed layer on the substrate, wherein the first layer of electrically conductive material is applied to the metal seed layer.

86. The method of claim 85, further comprising applying a photoresist layer over the metal seed layer.

87. The method of claim 86, further comprising patterning the photoresist layer to open windows in the photoresist layer to the metal seed layer.

88. The method of claim 87, wherein patterning the photoresist layer comprises patterning a mask defining the winding elements of the lower set of winding elements, exposing the photoresist layer through the mask, and developing the photoresist layer to open windows in the photoresist layer to the metal seed layer in the photoresist layer.

89. The method of claim 87, wherein applying the first layer of electrically conductive material comprises depositing an electrically conductive material on the metal seed layer in the windows defined by the photoresist layer to form the winding elements of the lower set of winding elements.

90. The method of claim 89, wherein the first layer of electrically conductive material is electroplated onto the metal seed layer in the windows defined by the photoresist layer.

91. The method of claim 90, wherein the electrically conductive material of the first layer is comprised of at least one of copper, gold, and silver, and alloys thereof.

92. The method of claim 89, further comprising removing the metal seed layer.

93. The method of claim 92, wherein removing the metal seed layer comprises etching away the metal seed layer in accordance with a mask to facilitate electrical isolation of the winding elements of the lower set of winding elements.

94. The method of claim 92, further comprising applying a layer of polymeric material between the winding elements of the lower set of winding elements.

95. The method of claim 94, further comprising heating the polymeric material to cross-link the polymeric material.

96. The method of claim 94, wherein the polymeric material comprises baked photoresist, polyimide, and BCB.

97. The method of claim 85, wherein applying a metal seed layer comprises applying alternating layers of chrome and electrically conductive material to the substrate.

98. The method of claim 85, wherein applying a metal seed layer includes at least one of sputtering and vacuum depositing the metal seed layer.

99. The method of claim 84, further comprising applying an insulation layer over the winding elements of the first set of winding elements.

100. The method of claim 84, further comprising forming an oxide layer on a silicon substrate and forming a silicon device layer on the oxide layer, wherein the first layer of electrically conductive material is applied to the silicon device layer.

101. The method of claim 81, wherein etching away at least a portion of the second layer of the substrate comprises release etching at least a portion of the second layer of the substrate.

102. The method of claim 74, wherein releasing the MEMS component from the substrate comprises etching away at least a portion of the top layer of the substrate.

103. The method of claim 102, wherein etching away at least a portion of the top layer of the substrate comprises deep silicon etching at least a portion of the top layer of the substrate.

104. The method of claim 70, further comprising cleaning the MEM device with supercritical carbon dioxide.

105. A method of fabricating a plurality of MEMS devices on a substrate, each MEMS device including an electromagnetic actuator and a corresponding actuable element, the method comprising:

constructing a plurality of electromagnetic MEMS actuators on the surface of the substrate by building a plurality of electrically conductive coils on the surface of the substrate, each coil being arranged to form a gap between two ends of the coil, and

forming a plurality of actuable elements from a layer of the substrate at positions on the substrate to facilitate displacement of at least a portion of each actuable element relative to the corresponding gap upon activation of the corresponding electromagnetic actuator.

106. The method of claim 105, further comprising die cutting the substrate to separate at least two of the plurality of MEMS devices.

107. The method of claim 105, further comprising cleaning the plurality of MEMS devices with supercritical carbon dioxide.